REDFISH BAY SOCKEYE SALMON STOCK ASSESSMENT

2002 ANNUAL REPORT

by

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ANNUAL REPORT SUMMARY PAGE

Title: Redfish Bay Sockeye Salmon Stock Assessment Study Number: FISO2-017

Investigators/Affiliations: Jack Lorrigan Sitka Tribe of Alaska; Margaret Cartwright and Jan Conitz/Alaska Department of Fish and Game, Division of Commercial Fisheries; Terry Suminski/U.S. Forest Service, Sitka Ranger District; Benjamin Van Alen! U.S. Forest Service, Juneau Ranger District.

Management Regions: Tongass National Forest, Southern Baranof Island Wilderness Area.

Information Type: Stock Status and Trends

Issues Addressed: Sockeye population viability and potential loss of subsistence opportunity. Assure that escapement levels are adequate to provide sustainable subsistence harvests. Redfish Bay is the fifth most important producer of sockeye salmon for subsistence users in Sitka. Sitka is the largest rural community in Southeast Alaska that has Customary and Traditional use Determination. Reliable estimates of the escapement and subsistence harvest are needed.

Study Cost: $572,025 (3 years)

Study Duration: May 2001 to May 2004

Key Words: Baranof Island, escapement, hydroacoustics, Tumakof Lake, illegal fishing, over exploitation, limnology, mark-recapture, *Oncorhynchus nerka,* radio tagging, sockeye salmon, subsistence, weir, Tribal co-management, customary and traditional use, ancient archaeological sites.\

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We also acknowledge the expert assistance of the following groups and individuals at ADF&G: John Edmondson and the Soldotna Limnology Lab crew for processing of the zooplankton samples; Iris Frank, Mark Olsen and the Commercial Fisheries Scale & Age Lab crew for analysis of scale, length and age data; Xinxian Zhang for advice and programming for statistical analysis; Renate Riffe for the creel census study design, data analysis and results; Hal Geiger for editing, support and advice. We thank Ken Bellows of Air Sitka, the pilots of Harris Air, skipper Barbara Bingham of the m/v Raven's Fire, and the hardworking crew of the m/v Eyak for safely transporting people and gear to the field site. Finally, we wish to thank the subsistence fishers and members of the Sitka Tribe of Alaska who took part in the creel survey interviews, and whose interest in the continuing use and conservation of the Redfish Bay sockeye runs provide the motivation for this project.

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ABSTRACT

In the summer of 2002, the Sitka Tribe of Alaska, Alaska Department of Fish and Game, and the United States Forest Service undertook a cooperative project to evaluate the effects of an illegal harvest in 2000 and the subsequent legal subsistence harvest of sockeye salmon at Redfish Bay, Alaska. Adults were enumerated through a weir, a portion of which were sampled for sex, length, and scales; another portion was also marked and later recaptured on or near their spawning grounds. The weir count of adult sockeye was 24,128. The escapement estimate generated from the associated mark-recapture experiment was 34,015 sockeye salmon, with a 95% confidence interval of 28,442 – 43,443 fish, and a coefficient of variation (cv) of about 10%. The discrepancy between the weir count and the mark-recapture estimate may have resulted from a later run of fish evident below the weir when it was discontinued. The harvest census of 1,309 sockeye salmon revealed a small portion of the run was actually impacted this year, at less than 5% of total returns. Plankton analysis appeared high and abundant but showed a distinct lack of the preferred *Daphnia sp* and other cladocerans. Age, sex, and length analysis also demonstrated that most Tumakof Lake sockeye salmon smolt after two years in freshwater, which makes their food requirements higher but also would enable their survival as larger individuals in the open ocean. For such a small lake the Redfish Bay/Tumakof Lake system is remarkably productive.

INTRODUCTION

This is the first year of observation for Redfish Bay/Tumakof Lake (ADF&G stream no. 113-13-10010; Figure 1) since 1971. At that time the weir was discontinued as it was felt that the sockeye runs were strong enough to sustain a comprehensive commercial fishing management plan. That statement comes from a Dept. of Interior document (Hilsinger 1955 and ADF&G documents) describing weir activities by the USFWS in 1955 and then by ADF&G personnel for a 6 year period starting in 1966 and ending in 1971. In the year 2000 however, an illegal over-harvest of sockeye salmon occurred in Redfish Bay inside the regulatory markers. The unlawful harvest of 8,100 fish added to the legal harvest of 9,779 fish made for a total harvest of 17,879 sockeye, a significant portion of the 2000 escapement to this system. The over-harvest caused concern about future year classes and future subsistence access to sockeye which Sitka residents are relying on. Funding was pursued through the FRMP for an initial three year study, it was awarded and the Sitka Tribe has taken responsibility of operating a weir, conducting the mark recapture in the lake and progress report and final report writing for the Redfish Bay project.

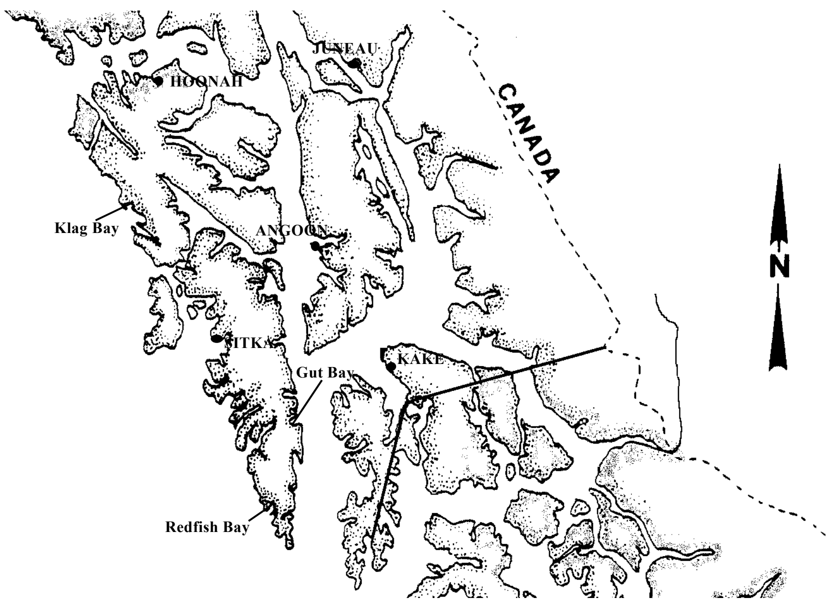

Figure 1. Redfish Bay location in relation to Sitka, Alaska.

Sitka is the largest rural community in Alaska, with customary and traditional use determinations for many species including sockeye salmon. Tumakof Lake is noted as one of the largest producers of sockeye salmon in Southeast Alaska for a lake its size (data calculated by Dr. Dick Crone and reported in an ADF&G memo from Robert Delong to Paul Larson, 3/16/87), and is an important resource for the people of Sitka. Redfish Bay ranks fourth in importance, after Redoubt, Klag and Necker Bays, for subsistence users in Sitka. Its significance has increased in recent years as a consequence of conservation closures at Redoubt Lake, improved marine technology and a desire to "get away from the crowd" during an intense harvest season. Pressure on this system may be expected to increase in response to increased fishing pressure in other systems closer to Sitka. Historical data on sockeye salmon escapement and productivity at Redfish Bay comes from two known periods of observation. The first is from Jefferson F. Moser USN in a report from 1898 and later published in 1899 for the United States Fish Commission (Steamer Albatross). The report describes ongoing salmon canning operations and the large numbers of sockeye attributed to Redfish Bay. It must be noted that some fish reported were mixed from other lakes but even with this an estimated 103,541 sockeye in 1896, and 64,509 sockeye in 1897 is noteworthy. This incredible abundance encouraged the building of a cannery in Redfish Bay to supply product for sale in the continental United States and other markets. The other report is from the Alaska Department of Fish and Game beginning in 1966 and ending in 1971 (Hilsinger 1955 and ADF&G documents) and also describes USFWS weir efforts at Redfish Bay in 1955. These reports describe weir activities and locations during their tenure at Redfish Bay. They also describe the wide range of sockeye returns, from 14,176 in 1955 with the USFWS weir and 66 ,000 during one year in 1966. Both returns indicate the ability of this system to produce large numbers of fish.

Shee Lunaaxk Gatheeni, or Redfish Bay traditionally belonged to the Kiks'adi clan of the Sheetka Kwaan. It was also known as just Laanaak, the name of a Kiks' adi chieftain who lived in the area (Goldschmidt and Haas 1998). Since there are no significant salmon streams southward of Redfish Bay along the coast, and since Redfish has a large sockeye run available, there is little doubt of its importance to the local Tlingit. A significant find in the estuary area proves Redfish's historical importance. A shard of hemlock basket was uncovered and dated near 5,000 years old (Robi Craig STA 2001, personal communication). Also, ancient weir stakes are visible on the beach at low tide indicating a substantial historical indigenous fishing effort. While most of the fishing occurs in Redfish Bay, the sockeye salmon spawn and rear in the hourglass shaped Tumakof Lake, which is connected to the Bay by a stream approximately ½ mile long. No inlet stream flows into this lake in a manner conducive to traditional perceptions of salmon spawning. Sockeye adults have been observed since 1898 spawning on the beaches of the lake at the north end (Moser 1899).

Subsistence harvests of sockeye salmon at Redfish Bay have increased significantly in the past 18 years. In 1985 a total of 7 permits were issued with 128 fish harvested. In 2002, 21 permits were issued and 1,101 fish were reported harvested. Between 1985-91, the average annual sockeye harvest was 237 fish on an average of 6 permits. Since 1992 the average sockeye harvest jumped to 690 on an average of 18 permits per year. The maximum annual harvest was reported in 1994, a total of 1,111 sockeye salmon on 22 permits, or 50.5 fish per permit holder. The commercial harvest at Redfish Bay since 1960 has been open only 26 years, with an average of 6,922 fish harvested on those open years. The lowest catch was recorded in 1965 at 7 fish. The 2 highest years were 1968 with 23,217 sockeye harvested and 2000 with 17,867 harvested (ADF&G documents).

The Redfish Bay Sockeye Salmon Project is one of several new projects, initiated in 2001 and funded through the U.S. Fish & Wildlife Service Fisheries Resource Monitoring Program, to assess significant subsistence sockeye runs in southeast Alaska. In addition to escapement data, fisheries harvest and lake ecology data are being collected at Redfish Bay to support long-term escapement goals that incorporate lake productivity modeling. The study plan includes an assessment of the lake's physical characteristics, which support primary production, and the secondary production of its zooplankton populations. Juvenile population parameters, including density, size, and age composition, will be estimated as indicators of sockeye salmon response to conditions within the lake. The harvest and escapement data we are collecting from returning adults will enable run reconstruction by brood year, and will indicate the overall status of the Tumakof Lake sockeye salmon stock. This report summarizes the sockeye salmon stock assessment data collected in the first year of the project.

OBJECTIVES

1) Estimate the escapement of sockeye salmon and other salmonids into the Tumakof Lake system, with the aid of a weir on the outlet stream of the lake and additional mark-recapture censuses, such that the estimates are within 10% of the actual abundance 95% of the time.
2) Estimate the subsistence harvest of sockeye salmon from Redfish Bay such that estimate is within *15%* of the actual harvest 90% of the time.
3) Estimate the age, length, weight, and sex composition of the sockeye salmon in the Tumakof Lake escapement such that these estimates are within 5%, 95% of the time.
4) Estimate a conversion between in-lake survey/mark-recapture estimates and the total estimated escapement of sockeye salmon such that the estimates have a coefficient of variation less than 20%.
5) Estimate the in-lake productivity of Tumakof Lake using established ADF&G limnological sampling procedures.

Secondary objectives, depending on availability of funding and characteristics of system:

6) Estimate the sockeye fry rearing density within Tumakof Lake, using hydroacoustic methods, if feasible such that the estimate is within 10%, 90% of the time.
7) Estimate the age, sex and size composition of sockeye smolt such that these estimates are within 10%, 90% of the time.
8) Conduct radio tagging survey to estimate spatial distribution of spawning sockeye within the Tumakof Lake system.

After three to five years:

9) Make initial estimates of biological escapement goal ranges and sustainable escapement thresholds for sockeye salmon based on current estimates of adult escapements, terminal runs, rearing juvenile densities, smolt age and size, in-lake productivity, and limnology-based habitat capacity modeling.

Changes to Objectives

The precision estimates for the population variables to be estimated were incorrectly stated in the original objectives listed above. Objectives 1, 2, 3, and 6 will therefore be changed for the subsequent years of the project as follows:

1) Estimate the escapement of sockeye salmon and other salmonids into the Tumakof Lake system, with the aid of a weir on the outlet stream of the lake and additional mark-recapture censuses, so that the estimated coefficient of variation is less than 10%.
2) Estimate the subsistence harvest of sockeye salmon from Redfish Bay, so that the estimated coefficient of variation is less than 15%.
3) Estimate the age, length, weight, and sex composition of the sockeye salmon in the Tumakof Lake escapement, so that the estimated coefficient of variation is less than 5%. Estimate the sockeye fry rearing density within Tumakof Lake, using hydroacoustic methods, so that the estimated coefficient of variation is less than 10%.

The following objectives have been dropped:

4) Estimate a conversion between in-lake survey/mark-recapture estimates and the total estimated escapement of sockeye salmon such that the estimates have a coefficient of variation less than 20%.
7) Estimate the age, sex and size composition of sockeye smolt such that these estimates are within 10%, 90% of the time.
8) Conduct radio tagging survey to estimate spatial distribution of spawning sockeye within the Tumakof Lake system.

METHODS

Study Site

Redfish Bay (N 56° 22.387 W 134° 51.409) is the most southern sockeye lake on Baranof Island and the last significant salmon system on its southwestern coast before the shoreline culminates at Cape Ommaney. Redfish Bay was and is an important embarkation point to cross the confluence of Chatham and Sumner straits to head south to Prince of Wales Island and points beyond. The Tumakof Lake drainage is approximately 1,062 ha. Numerous cascades falling from steep surrounding mountainsides feed the lake. The lake is hourglass shaped, oriented lengthwise north to south. Its depth is 99 m at its deepest with an average depth of 51 m (Figure 2). The lake is drained by a stream, approximately ½ mile long, flowing mainly over bedrock and large cobble. The main falls in this stream is a bedrock notch and occurs about 20 m above the weir with a 3 m meter drop at about a 40 degree angle. The falls are angled towards the right bank looking upstream and it takes a strong jumper to clear this obstacle. Sockeye and coho have little difficulty negotiating the short cascades, but pink and chum were never observed above the second falls. In addition to sockeye salmon (*Oncorhynchus nerka*), Tumakof Lake and stream support small runs of coho (*0. kisutch*) salmon and Dolly Varden (*Salvelinus malma*). Chum (*0.* *keta*) and pink salmon (*0. gorbushca*) have also been observed in the lower Tumakof Lake outlet.

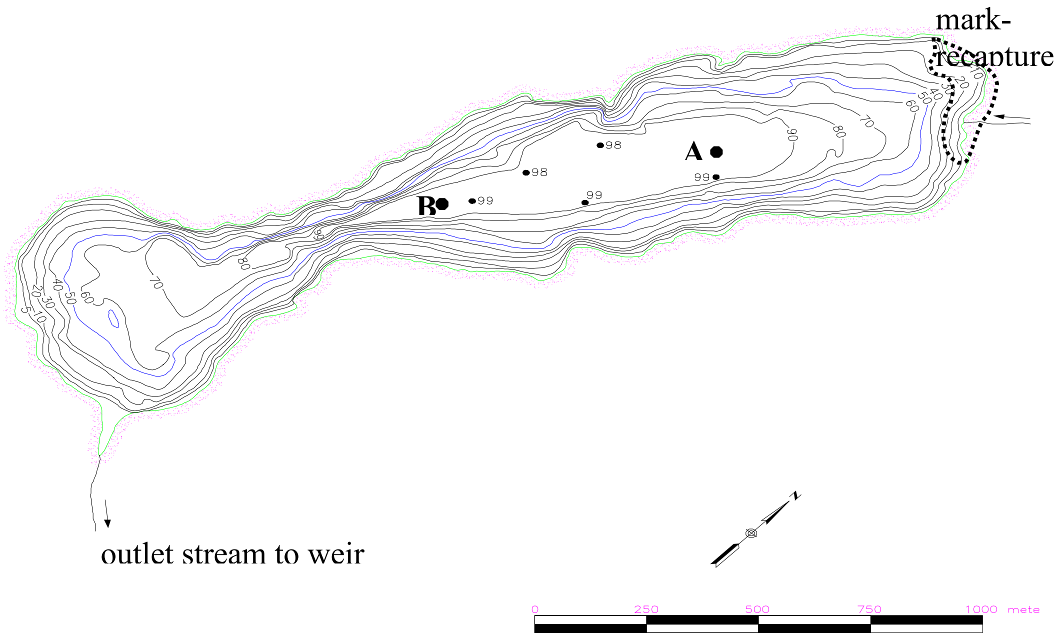

Figure 2. Tumakof Lake bathymetric map showing two permanent limnology sampling stations (A, B) and locations of recapture efforts.

Juvenile Sockeye Population Assessment

Juvenile sampling was not conducted in Tumakof Lake this year. The reason for this is the presence of many large logs and deadfall that have fallen into the lake from the surrounding steep mountainsides. The lake edge drops off at a sharp angle and the logs are not able to permanently situate along the shoreline. When the wind blows, the logs are free to wander around the lake. The unpredictable nature of the surface condition on the lake on any given day made the hydro-acoustic survey impractical and unsafe since the survey must be done at night. Therefore, no hydro-acoustic or trawl data could be gathered for 2002.

Adult Escapement Estimates

Weir

A weir was installed in the outlet stream of Tumakof Lake to directly count all salmonids entering the lake. The accuracy of the weir count of sockeye salmon was verified with a mark-recapture estimate of escapement, using the weir as a marking platform. Biological sampling was also conducted at the weir, including species identification, sockeye salmon mid-eye to fork length measurements, and scale collection for aging.

A wooden tripod, picket and channel type weir was constructed across the Tumakof Lake outlet stream about 75 m upstream from the estuary. Eight tripods and 7 picket panels, each holding 53 pickets, were used. The weir was reinforced against high water and possible washout using sandbags, and was held in place by means of cables tied to trees upstream. Migrating fish were funneled into a 4 ft x 4 ft x 8 ft box frame trap, from which they were counted, marked, measured and sampled, and passed upstream. The weir was operated continuously from 21 June to 18 Sept.

Weir/Spawning Grounds Mark Recapture Study

A stratified two-sample mark-recapture study was conducted to test the integrity of the weir by providing an estimate of sockeye salmon escapement into Tumakof Lake. Marks given sockeye salmon at the weir were stratified by time, to allow separate estimation of different parts of the run, should the weir fail or violations of mark-recapture assumptions occur during some part of the run (Arnason *et al*. 1995*).* A constant 50% daily marking rate was specified in the operating procedures, but the number of fish passing the weir, especially on peak days, was larger than expected, so a reduced marking fraction of 15-20% was maintained throughout the run. The marking strata were from June 22 through August 6 (left pelvic), from August 7 through the 31st (right pelvic) and from September 1st through the 17th (dorsal clip).

Live and dead fish were examined in the spawning areas for marks and marked with a secondary (opercular punch) mark to prevent duplicate sampling. However, the crew was not able to distinguish between the different marking strata, and recorded these fish only as "marked" or "unmarked." Since a stratified population estimate could not be generated from these data, a "pooled Petersen" estimate was used in which all marking strata were combined into a single marking event and all recapture strata were combined into a single recapture event. The pooled Petersen estimate was used because it had the lowest variance and was free of calculation errors. A 95% confidence interval for the pooled Petersen estimate was constructed by pooling the data from all marking and all recapture strata and treating the pooled data as for a single estimate. We let C denote the number of fish examined for marks in the pooled second samples, and R denoted the number of fish in the pooled second samples with a mark. R is a random variable, and because sampling for marked fish was without replacement, R was assumed to be hypergeometrically distributed. However, when R is large compared with the size of the second sample, C, its distribution can be assumed to be approximately normal. We let $\hat{p}$ be an estimate of the proportion of marked fish in the population such that $\hat{p} = \frac{R}{C}$. Approximate confidence interval bounds were found first for $\hat{p}$, and their reciprocals were then used to construct confidence interval bounds for the Petersen estimate N^*. If $\hat{p} \geq 0.1$, and the size of the second sample C was at least the minimum given in Table 1, a 95% confidence interval for $\hat{p}$ was given by

$$\hat{p} \pm \left[1.96\sqrt{\left(1-\frac{C}{\hat{N}}\right) * \hat{p}(1-\hat{p})/(C-1)} + \frac{1}{2C} \right] \text{ (Seber 1982, equation 3.4).}$$

Table 1. Sample size criteria for using Seber's (1982) equation 3.4 to find 95% confidence interval for $\hat{p}$. For given $\hat{p}$, minimum sizes for the second sample C are indicated.

$\hat{p}$ (or 1-$\hat{p}$)	0.5	0.4	0.3	0.2	0.1
minimum C	30	50	80	200	600

Seber's (1982) equation 3.4 was also used when $\hat{p} < 0.1$ if $R > 50$. If these criteria were not met, the confidence interval bounds for $\hat{p}$ were found from Table 41 in Pearson and Hartley (1966). We let ($a_{0.025}$, $a_{0.975}$) represent confidence interval bounds for $\hat{p}$; the 95% confidence interval bounds for the Petersen population estimate N^* were found by taking reciprocals of the confidence interval bounds for $\hat{p}$ and multiplying by M,

$$\left(M * 1/a_{0.975} \, , \, M * 1/a_{0.025} \right).$$

A survey of Tumakof Lake was conducted on 20 August to determine which shorelines had the highest concentrations of available spawners. Sub-terrain ground charge from the surrounding cascades flowing underground through the upland shelf along the northern beaches attracted the highest visible number of spawning adults for capture. A second survey was made on 9 Oct., and a mark-recapture events were conducted 16 and 17 September and again on the 9th and 10th of October.

Adult Sockeye Salmon Population Age and Size Distribution

Scales, matched with sex and length data, were collected from adult sockeye salmon at the Redfish Bay weir to describe the age and size structure of the population. The sampling goal for each lake was 600 fish. Fish were selected systematically (e.g. every fifth fish) to prevent selection bias, through the entire run. Three scales were taken from the preferred area of each fish (INPFC 1963), and prepared for analysis as described by Clutter and Whitesel (1956). Scale samples were analyzed at the ADF&G salmon aging laboratory in Douglas, Alaska. Age and length data were paired for each fish sample. Age classes were designated by the European aging system where freshwater and saltwater years are separated by a period (e.g. 1.3 denotes 1-year freshwater and 3-years saltwater) (Koo 1962). Brood year tables were compiled by sex and brood year to describe the age structure of the returning adult sockeye salmon population. The length of each fish was measured from mid-eye to tail fork to the nearest millimeter (mm).

After the scales were aged, the scale samples were stratified by age and by sex. Let n be the total number of samples aged, n_k be the number of samples in stratum k, and N be the estimated escapement. The proportion of each stratum k was calculated by

$$\hat{p}_k = \frac{n_k}{n}.$$

The estimated standard error was derived from the binomial formula with correction for finite population size (Thompson 1992, p. 35-36):

$$SE(\hat{p}_k) = \sqrt{\left(1 - \frac{n}{N}\right)\frac{\hat{p}_k(1-\hat{p}_k)}{n-1}}$$

The estimated mean length and associated standard error for stratum k were calculated as the sample mean of a simple random sample (Thompson 1992, p. 42-43):

$$\bar{y}_k = \frac{1}{n_k}\sum_{i=1}^{n_k} y_{ki}\text{ , and } SE(\bar{y}_k) = \sqrt{\frac{1}{n_k}}\sqrt{\left(\frac{1}{n_k - 1}\right)\sum_{i=1}^{n_k}(y_{ki} - \bar{y}_i)^2}\ .$$

Subsistence Harvest Estimation Creel Survey

The study design for the Redfish Bay marine subsistence fishery was originally based on a stratified two - stage sampling design (Cochran 1977). The crew was able to interview all participants except for one individual. The fishing grounds, or access to them was easily visible from the camp. Thus, the two-stage study design was eliminated. A complete census was accomplished.

Data Analysis

Boat parties were stratified by fishery type, due to relative efficiencies of gear, and differing seasons for each gear type. Sport fishers used fishing rods, which were the least efficient method of capture. Subsistence fishers used gillnets and beach seines. We are confident all subsistence and sport boat parties were interviewed. Since all boat parties were interviewed, the harvest estimate was simply the sum the harvest. No variance estimate was calculated.

Limnology Sampling

Limnology sampling was conducted at two stations on Tumakof Lake to measure euphotic zone depth, temperature and dissolved oxygen, and to collect zooplankton samples. Physical measurements were only made at Station A, the deeper of the two, while zooplankton samples were collected at Stations A and B.

Light, Temperature, and Dissolved Oxygen Profiles

Underwater light intensity was recorded from just below the surface to the depth where measured intensity was one percent of the surface light reading, at 0.5 m intervals, using an electronic light sensor and meter (Protomatic). The vertical light extinction coefficients (K_d) was calculated as the slope of the light intensity (natural log of percent subsurface light) versus depth. The euphotic zone depth (EZD) was defined as the depth to which one percent of the subsurface light [photosynthetically available radiation (400-700nm)] penetrates the lake surface (Schindler 1971), and is calculated from the equation: EZD = 4.6205/ K_d (Kirk 1994). The euphotic zone depth defines the part of the lake where photosynthesis is possible.

Temperature and dissolved oxygen (DO) profiles were measured with a Yellow Springs Instruments (YSI) Model 58 DO meter and probe, in relative (%) and absolute (mg L^{-1}) values for DO and in ºC for temperature. Measurements were made at 1 m intervals to the first 10 m or the lower boundary of the thermocline (defined as the depth at which the change in temperature decreased to less than 1ºC per meter), and thereafter at 5 m intervals to within 2 m of the bottom (or 50 m). The dissolved oxygen meter reading at 1 m was calibrated at the beginning of a sampling trip using the value from a 60 ml Winkler field titration (Koenings *et al*. 1987). The DO profile was measured only on the first sampling trip in May.

Secondary Production

Zooplankton samples were collected at two stations using a 0.5 m diameter, 153 um mesh, 1:3 conical net. Vertical zooplankton tows were pulled from a maximum depth of 50 m, or 2 m from the bottom of the lake if shallower than 50 m, at a constant speed of 0.5 m sec^{-1}. The net was rinsed prior to removing the organisms, and all specimens were preserved in neutralized 10% formalin (Koenings *et al*. 1987). Zooplankton samples were analyzed at the ADF&G Commercial Fisheries Limnology Laboratory in Soldotna, Alaska. Identification to genus or species, enumeration, and density and biomass estimates were performed as in 2001 (Conitz *et al*. 2002; Koenings *et al*. 1987). Zooplankton density (individuals per m^2 surface area) and biomass (weight per m^2 surface area) were estimated by species and by the sum of all species (referred to as total zooplankton density or biomass).

RESULTS

Juvenile Sockeye Population Assessment

No juvenile population assessment was conducted because of logs covering a large portion of the lake, making it impossible to run sonar transects or trawl tows safely.

Adult Escapement Estimates

Weir

Sockeye escapement into the Tumakof Lake stream began on 22 June. By the weir removal date of 18 Sept. 24,128 sockeye had passed the weir, but there were still sockeye salmon in the bay that had not yet entered the lake. Peak escapement days were August 7th at 5,105, the 8th at 3,234 and the 21st at 1,775, also September 1st with 1,224 sockeye salmon, respectively, entering the Tumakof Lake stream (Figure 3). Coho salmon entered the stream between 30 July and 18 Sep., with a peak escapement count on 21 Aug. of 131 fish for a total of 891 coho. There is the possibility of an uncounted later run of coho salmon into this system after 18 Sept as they were also observed in the estuary. Peak daily escapement for all species was associated with increasing or peak flow levels in the creek. 8,159 pink salmon and 38 chum salmon passed the weir but were not able to pass the falls 25 meters upstream.

After the weir was pulled some sockeye still remained and were mixed with other species below the weir. On the 19th of September it was noted that a number of sockeye and coho, approximately 935, remained below the weir and did not attempt to move up into Tumakof Lake even after two separate significant rain events.

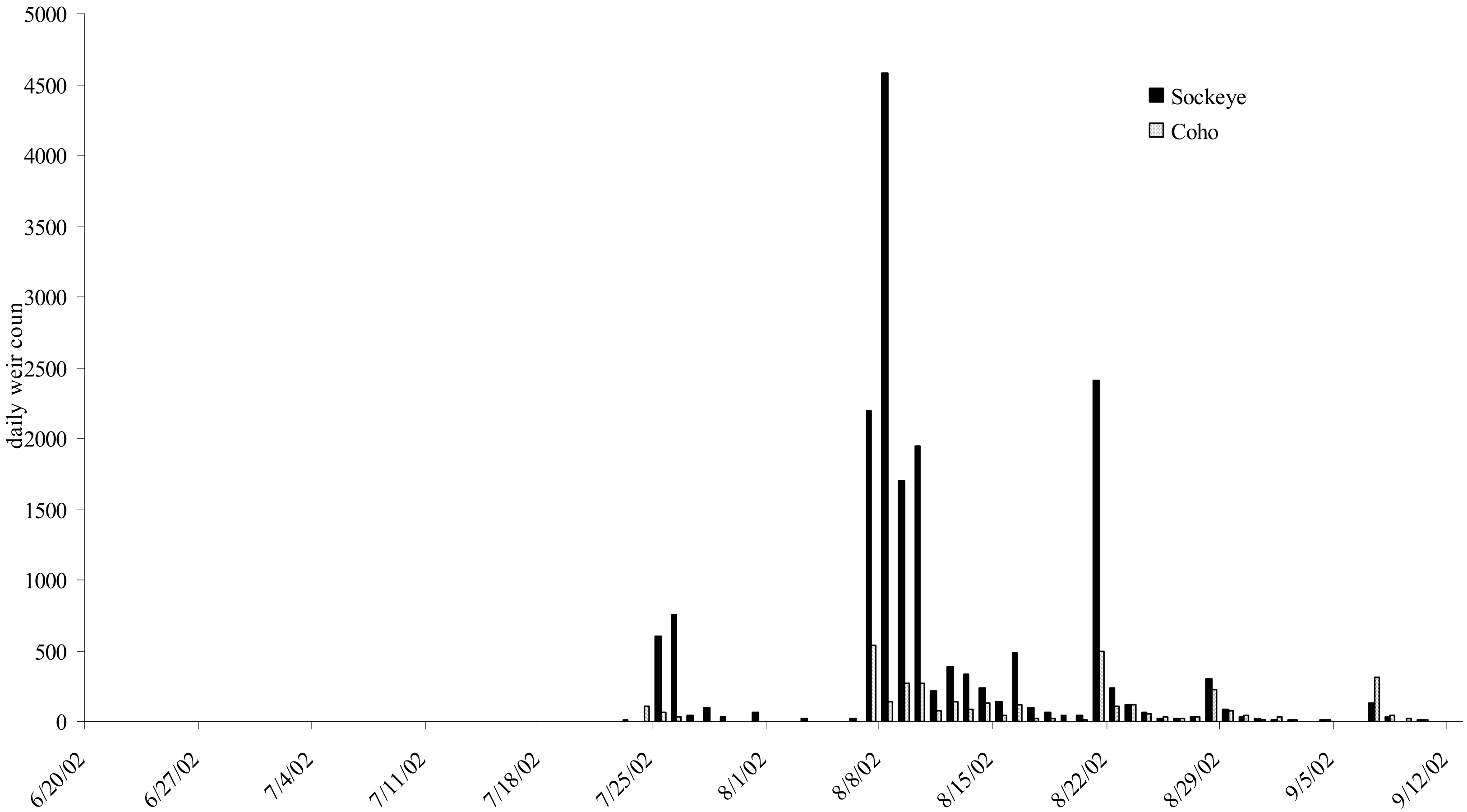

Figure 3. Daily escapement of sockeye and coho salmon into Redfish bay weir

Weir/Spawning Grounds Mark-Recapture Study

In the mark-recapture study of 3,591 fish were marked at the weir, for an overall marking rate of 15% of the run. A total of 82 marked fish were caught in a sample of 785 fish. The escapement estimate generated from this experiment was 34,015 sockeye salmon, with a 95% confidence interval of 28,442 – 43,443 fish, and a coefficient of variation (cv) of about 10%. This estimate is a 30% higher than the weir count, and the weir count was below the lower bound of the confidence interval. A possible explanation is that a large number of sockeye salmon entered the lake after the weir was pulled, before the October 9 and 10 recapture event.

Adult Sockeye Salmon Population Age and Size Distribution

Of the 591 sockeye adults sampled for age, length and sex, males comprised 65% of the sample. The large number of fish still holding below the weir when it was pulled and the tendency of salmonid females to return later to their natal spawning stream, may explain the lower number of females sampled. The dominant year class age-2.2. Their average length was 539 mm. The next dominant age class was age-2.3, at 27%; their average size was 595 mm. These two cohorts comprised 82% of the run. The rest of the run was comprised of everything from the smaller age- 1.1 jacks, averaging 370 mm in length, to the oldest and largest age-3.3 fish, averaging 610 mm (Tables 2 and 3). Of the 591 fish sampled only 8 individuals (1%) had 1 year freshwater and 99% of the run had 2–3 years freshwater, indicating most fish are smolting after at least a 2 year period in this productive lake and spending 1-4 years in the ocean.

Table 2. Age composition of adult Sockeye Salmon in Redfish Bay escapement by sex and brood year.

Brood Year	**1999**	**1998**	**1998**	**1997**	**1997**	**1997**	**1996**	**1996**	**1995**	**1995**	
Age	**1.1**	**1.2**	**2.1**	**1.3**	**2.2**	**3.1**	**2.3**	**3.2**	**2.4**	**3.3**	**Total**
Male											
Sample Size	1	1	42	2	217	7	88	28	1	2	389
Percent	0.2	0.2	7.1	0.3	36.6	1.2	14.8	4.7	0.2	0.3	65.6
Std. Error	0.2	0.2	1	0.2	2	0.4	1.4	0.9	0.2	0.2	1.9
Female											
Sample Size		1		3	108		72	17	2	1	204
Percent		0.2		0.5	18.2		12.1	2.9	0.3	0.2	34.4
Std. Error		0.2		0.3	1.6		1.3	0.7	0.2	0.2	1.9
All Fish											
Sample Size	1	2	42	5	325	7	160	45	3	3	593
Percent	0.2	0.3	7.1	0.8	54.8	1.2	27	7.6	0.5	0.5	100
Std. Error	0.2	0.2	1	0.4	2	0.4	1.8	1.1	0.3	0.3	

Table 3. Length composition of adult Sockeye Salmon in Redfish Bay escapement by sex and brood year.

Brood Year	1999	1998	1998	1997	1997	1997	1996	1996	1995	1995	
Age	1.1	1.2	2.1	1.3	2.2	3.1	2.3	3.2	2.4	3.3	Total
Male											
Avg. Length	370	520	362	570	539	389	596	541	615	620	530
Std. Error			2.6	20	1.9	5.3	3	4.6		10	3.7
Sample Size	1	1	42	2	215	7	88	28	1	2	387
Female											
Avg. Length		500		575	538		594	543	563	590	559
Std. Error		8.7		2.4	2.9		3.6	17.5	2.5		
Sample Size		1		3	108		72	17	2	1	204
All Fish											
Avg. Length	370	510	362	573	539	389	595	542	580	610	540
Std. Error	10	2.6	8	1.5	5.3	2.1	3.2	20.2	11.5	2.6	
Sample Size	1	2	42	5	323	7	160	45	3	3	591

Subsistence Harvest Estimation Creel Survey

Table 4. Complete count of sport and subsistence sockeye harvest at Redfish Bay, 2002.

Fishery type	Boats counted	Boats sampled	Sockeye total	Chum total	Pink total	Coho total
Subsistence	7	7	1,262	0	0	
Sport	8	7	47	0	0	1
Totals	15	14	1,309	0	0	1

The Redfish Bay subsistence fishery was open between 1 June and 30 August, 2002 and the sports fishery was open continuously through the year. Subsistence boats entered the area starting 15 July and ending on 16 August. At most, 2 subsistence boats fished on any given day and subsistence fishing occurred on only six days out of the 33 day period of active fishing between 15 July and 16 August. Sport fishers participated in the fishery during the same time period as the subsistence fishing. Participants in the two fisheries used different gear types. Rod and reel were used by sports fishers; beach seines and one dip net were used in the subsistence fishery. The technicians reported no difficulties in viewing all areas of both fisheries, and were very confident they interviewed everybody that came into the bay because the acoustics of the bay allow motors to be heard very easily. In the absence of other information, we will assume that the technicians interviewed all boat parties. There was one missed interview; the fishermen was observed fishing with sport gear for approximately 30 minutes, landing two snagged fish in full view of the crew, before he departed. These fish were included in the total sport harvest. Total sockeye salmon harvest was counted at 1,309 fish and the seven subsistence fishers harvested 96% of the total catch (1,262 fish). The average subsistence harvest per boat was 180 sockeye salmon. Because we do not check permits on the fishing grounds, we do not know how many proxy permits were being fished by these fishers. By comparison, the ADF&G database showed a preliminary sockeye harvest for 2002 of 1,101 sockeye salmon reported by 26 permit holders, as of May 8, 2003 (Bill Davidson ADF&G, personal communication 2002). It is expected that the reported harvest for 2002 will increase prior to the beginning of the 2003 season because fishers are required to return last year's permit before being issued one for the current year. Harvest of other salmon species was negligible (Table 4). Sports fishermen caught 47 sockeye salmon, and one coho salmon. Harvest of other salmon species was negligible.

Limnology Sampling

Limnology sampling was conducted in Tumakof Lake on 31 May, 11 July, and 28 Aug. The fourth sampling data in October was missed because bad weather made it too dangerous to fly into the lake. Physical data (light, temperature, and dissolved oxygen) were collected at the main sampling station A, and zooplankton samples were collected at both sampling stations A and B, on each date. Unfortunately, the zooplankton samples from 28 Aug. were lost or misplaced.

Light, Temperature, and Dissolved Oxygen Profiles

The mean euphotic zone depth (EZD) was about 10 m in Tumakof Lake in 2002 (Table 5). The minimum depth for the season occurred in August.

Table 5. Euphotic zone depths in Tumakof Lake, 2002.

Sample date	**EZD (m)**
31-May	12.12
11-Jul	14.22
28-Aug	8.06
seasonal mean	10.34

Tumakof Lake was beginning to warm in the surface layer on the first sampling at the end of May, and became thermally stratified by the 11 July sampling date (Figure 4). The thermocline had deepened the late Aug. sampling date but was beginning to weaken. The maximum epilimnetic temperature was in July at 15.1 ^{o}C, and the minimum temperature in the hypolimnion was about 4^{o}C at all three sampling dates. Dissolved oxygen (DO) levels were high throughout the first 50 m of the water column in late May (Table 6).

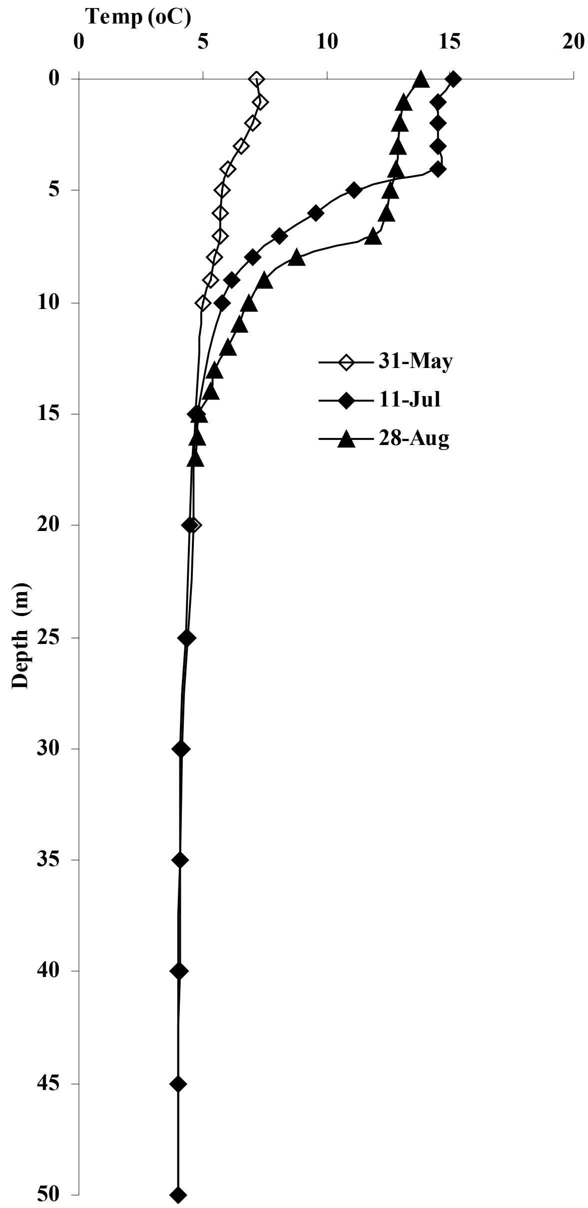

Figure 4. Temperature profiles in Tumakof Lake at Station A on 31 May, 11 July, and 28 Aug., 2002.

Table 6. Dissolved oxygen (DO) profile from Tumakof Lake, Station A, on 31 May 2002, as % O_2 saturation.

Depth (m)	Dissolved O_2 (% Saturation)
0	113.5
1.0	111.6
2.0	113.2
3.0	112.2
4.0	110.4
5.0	110.2
6.0	109.4
7.0	109.2
8.0	108.4
9.0	106.0
10.0	105.0
15.0	103.3
20.0	102.5
25.0	101.5
30.0	101.5
35.0	99.9
40.0	100.0
45.0	99.3
50.0	99.8

Secondary Production

Major taxa of macro-zooplankton identified in water samples from Tumakof Lake were cladocerans *Bosmina* sp., *Daphnia longiremus*, and *Holopedium* sp., and copepod *Cyclops* sp. Zooplankton abundance was high in Tumakof Lake, with mean biomass from two sampling dates of 285 and 625 mg·m^{-2} at station A and B, respectively (Table 7). Mean density from two sampling dates was about 165,000 and 270,000 zooplankters ·m^{-2} at stations A and B, respectively (Table 8). The zooplankton population was dominated by the copepod *Cyclops*, a less desired prey for sockeye salmon; *Cyclops* sp. represented about 70% of the biomass and about 50% of the total zooplankton abundance. The small cladoceran *Bosmina* was the next most abundant zooplankton taxon in Tumakof Lake samples, and small but measurable proportions of *Daphnia longiremus* were also present in the samples.

Table 7. Size and biomass of macrozooplankton in Tumakof Lake, 2002. Mean lengths are weighted by density (numbers · m^{-2}) at each sampling date and seasonal mean biomass is based on the weighted mean length. Only two samples dates are represented, May and July. Ovigorous (egg-bearing) individuals in each taxa were measured separately.

	Average Length (mm)				
Station A	**31-May**	**11-Jul**	**Weighted Mean Length (mm)**	**Seasonal Mean Biomass ($mg \cdot m^{-2}$)**	**% of Total Biomass**
Diaptomus					
Cyclops	0.86	0.86	0.86	187.5	65.9%
Ovig. Cyclops	1.07	1.20	1.10	4.3	1.5%
Bosmina	0.46	0.45	0.45	91.7	32.2%
Ovig. Bomsina					
Daphnia l.	0.58	0	0.58	1.2	0.4%
Ovig. Daphnia l.					
Holopedium	0.50	0			
			Total Seasonal Mean Biomass	285	100.0%
Station B					
Diaptomus					
Cyclops	0.84	0.89	0.86	433.9	69.4%
Ovig. Cyclops	1.07	1.15	1.12	15.0	2.4%
Bosmina	0.56	0.49	0.50	172.7	27.6%
Ovig. Bomsina	0.64		0.64	0.5	0.1%
Daphnia l.	0.62	0.77	0.68	3.0	0.5%
Ovig. Daphnia l.	1.14	1.38			
Holopedium	0	0			
			Total Seasonal Mean Biomass	625	100%

Table 8. Density (number · m^{-2}) of macrozooplankton by taxon in Tumakof Lake, 2002.

Station A	**31-May**	**11-Jul**	**Seasonal Mean**	**% of Total Numbers**
Diaptomus				
Cyclops	102,564	41,161	71,863	43.5%
Ovig. Cyclops	1,528	408	968	0.6%
Bosmina	11,038	87,213	49,125	29.8%
Ovig. Bomsina	0	0	0	
Daphnia l.	1,698	0	849	0.5%
Ovig. Daphnia l.		0	0	
Holopedium	0	0	0	
Chydorinae				
Copepod nauplii	21,396	63,169	42,282	25.6%
Seasonal Mean Density, All Taxa			**165,087**	
Station B				
Diaptomus				
Cyclops	197,911	134,148	166,030	61.2%
Ovig. Cyclops	2,292	4,245	3,269	1.2%
Bosmina	12,990	133,724	73,357	27.0%
Ovig. Bomsina	255	0	127	0.0%
Daphnia l.	1,783	1,274	1,528	0.6%
Ovig. Daphnia l.	0	0	0	
Holopedium				
Chydorinae				
Copepod nauplii	34,386	19,952	27,169	10.0%
Total Seasonal Mean Density			**271,481**	

DISCUSSION

It appears that the sockeye salmon returns this year to Redfish Bay were healthy and the terminal sport and subsistence fisheries harvest of 1,309 was a relatively small portion, about 5%, of the total run. Subsistence harvest and escapement counts appear to be consistent with previous information. The average reported subsistence harvest of sockeye salmon during the last decade at Tumakof Lake was about 632 and a high harvest of about 1,111 fish was reported in 1994. Because the harvest is generally under reported on the permits, it is likely that the 2002 harvest of 1,101 fish is an underestimate, and the true harvest was above the average for the decade. The weir count of sockeye escapement into Tumakof Lake was about 30% lower than the mark-recapture escapement estimate. It is likely that a large number of fish entered the lake in the fall after the weir was removed. This phenomenon was noted in 1898 and again during the ADF&G tenure at Redfish Bay, when the crews felt the bulk of the run had ascended the stream and the monitoring barrier was removed, it was observed that a number of fish remained below the weir through late September and October (Hilsinger, 1971; Moser 1899). Inter-annual variation of sockeye salmon escapement into Tumakof Lake may be large.

The 2001 investigation plan included an independent estimate of escapement by means of a spawning grounds mark-recapture study and a radio tagging study to collect information about distribution of sockeye spawning adults in the Tumakof Lake system. By comparing this information to the weir data in years when the weir is operated, it may be possible to accurately index mark-recapture or visual survey estimates to total escapement and thus avoid the high cost of running a weir in future years (Conitz *et al.* 2002). For several reasons, the crew was unable to carry out the surveys and mark-recapture events according to the study design during the 2002 season. Radio tagging is too expensive and was dropped for the remainder of this project.

The spawning habitat in Tumakof Lake is atypical, in that much of it consists of large cobbles and boulders on a steep slope, without a flat bottom or gravel. The margins of the lake are steep with no stream for adults to move into to spawn. However, mark-recapture events conducted late in the season demonstrated that some of these fish could be captured, counted, and marked on the lake shore. Three beaches on the north end of the lake were identified as fishable with a seine in 2002 and should be targeted for mark-recapture work in the 2003 season. Spawning appears to begin sometime in late August and continues through November. According to Moser (1899), sockeye were observed in the spawning area well into November with bright fish occasionally present. Timing of mark-recapture and survey events should bracket the beginning and end of the spawning period, between about 20 Aug. and 30 Nov. Another possibility is to keep the weir in longer to ensure the latter portion of the run is evaluated. Fish capture methods may need to be modified to be effective in the Tumakof Lake habitat. Although the Tumakof Lake system does present some difficulties for surveying and capturing sockeye salmon, it is a relatively small system and can be completely surveyed in one day.

There are no previous estimates of juvenile populations in Tumakof Lake, and we were not able to complete a fry estimate in 2002; hopefully a juvenile survey can be conducted in 2003. Alternative methods of fry abundance indexing may need to be explored since the surface conditions on Tumakof Lake are so unique. It is heavily littered with logs from the surrounding hillsides, which are frequently distributed across the surface of the lake preventing transect surveys. An alternative may be a smolt weir in the spring.

Macro-zooplankton abundance appeared normal to high, but *Daphnia* populations are very low. Species diversity also appears to be low in Tumakof Lake. The suspected large population of juveniles in the lake, including many that stay for two years, it is a possibility that the more desirable prey species, especially *Daphnia*, are being cropped down.

The age structure of the adults, with so many having two freshwater years, definitely requires more scrutiny since this system is appears to be very productive. Normally, in productive lakes with a plentiful food supply, sockeye smolt after one year, but this is not the case in Tumakof Lake. Could the high proportion of sockeye adults with two freshwater years be attributed to better survival of two-year-old smolts that can emigrate directly to the open ocean without much delay in an inside water environment? Redfish Bay is clearly an interesting system to investigate further.

Results from this project may address some of the concerns expressed by fisheries managers and subsistence users about fishing at Redfish Bay. In past years, managers and fishers had observed large numbers of sockeye salmon staging off the mouth of the Tumakof Lake outlet stream. The timing of terminal area fishing with respect to escapement timing was closely observed this year and does not appear to be a problem. Almost all the significant subsistence fishing took place over three and a half weeks, from 19 July to 10 August. There were several peaks in escapement through most of July and August, including one around 7 and 8 August, near the end of the peak of subsistence fishing. However, it does appear that escapement timing is somewhat associated with rainfall and water level in the Tumakof Lake stream, with fish waiting in the estuary for higher water, so it is important to continue monitoring both escapement and harvest timing to ensure that problems do not develop.

As in all the sockeye salmon projects, additional years of sampling are needed in order to define the relationship between escapement levels and lake productivity in Tumakof Lake. We will continue to attempt to assess sockeye fry and zooplankton populations, light and temperature, and adult returns. The overlapping data collected from the various life history stages of sockeye salmon and the environmental factors that affect them will help future managers to ensure sustainable harvest levels and continued productivity of the Tumakof Lake sockeye salmon populations.

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